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Atmospheric Transmission and Emission in the 16μ to 28μ Region at Various Altitudes

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ABSTRACT

Information conerning the variation of atmospheric transmission in the 16μ to 30μ region with altitude was obtained during a balloon flight. Data concerning the atmospheric emission in the same wavelength region were obtained during a second balloon flight with different instrumentation. The instrumentation used in the studies is discussed and some of the data obtained during these flights are presented. These data contain information concerning the distribution of water vapor in the stratosphere and they have been analized to determine the H_2O mixing ratio versus altitude profile. This profile is presented.

I. INTRODUCTION

The performance of many infrared systems which operate in the earth's atmosphere is limi d by atmospheric effects. These effects include the absorption of the infrared radiation emitted by the target in traversing the atmospheric path to reach the system sensor and also to the increase in the system noise due to the background radiation emitted by the atmosphere. Most endoatmospheric systems are designed to operate where these atmospheric effects will be a minimum, i.e., the so-calied atmospheric "windows".

While the region beyond 16μ can not be called a "window", the major atmospheric absorption features in this region are due to H_2O and as a result, this wavelength region becomes relatively "transparant" at the higher altitudes since the amount of water vapor decreases rapidly with altitude. A series of balloon flights was made under this program and the preceding program to investigate the atmospheric emission and transmission in this wavelength region as a function of altitude. The data obtained during these flights and their analyses are presented in this report.

II. INSTRUMENTATION

Three different instruments were used to obtain the data contained in this report. Data concerning the atmospheric transmittance in this wavelength region were obt ed by studying the variation of the solar spectrum with altitude. The instrumentation used in this study consisted of a biaxial pointing control which was used to orient a plane mirror so that the solar radiation was imaged by a 1 1/2m f/5 telescope onto the entrance slit of a spectrometer. The spectometer was a 1/2 meter Czerny Turner instrument. The unit employed a tuning fork chopper which interrupted the radiation after the first pass through the instrument. The radiation then passed through the instrument the second time and was imaged onto a Ge:Cu photoconductor which was used as a detector. The signal from the detector was amplified, synchronously rectified and recorded on board by means of a digital magnetic tape recording system. The data were also telemetered to the ground by means of an FM/FM telemetry system. The instrumentation was protected by a gondola system constructed of brazed conduit which protected the instrumentation when it was returned to the ground via parachute. Primary power for the operation of the various instruments was provided by a silver-zinc battery.

The second unit used to obtain data was a 1/3 meter grating spectrometer of Cassegrainian design. A tuning fork chopper was used to interrupt the incoming radiation at a 156 Hz rate. In this case, the chopper was placed at the entrance aperture and the radiation was single passed. The whole unit was enclosed in a container which was cooled to liquid nitrogen temperature. The spectrometer did not employ any fore-optics but rather its field of view was determined by the entrance slit. For this study the field of view was chosen to be approximately 10° square. Since the instrument was operated at liquid nitrogen temperatures and the entrance slit was open to the atmosphere provision had to be made to keep H_2O and CO_2 frost from forming on the optics. This was accomplished by forming a conical cavity immediately in front of the entrance slit. This opened out into a cylinder in which a series of plates with increasing diameter holes are moun-

ted. The nitrogen gas which boils off from the liquid nitrogen used as coolant is allowed to enter the rear of the spectrometer and to vent out the entrance slit. This flows on out the baffling system and keeps frost from forming anywhere within the field of view of the instrument. The system also acts as an optical baffle to keep stray radiation from reaching the detector. The detector used in the instrument was a Ge:Cu photoconductor which was mounted in a one liter liquid helium dewar. The dewar was equipped with a KRS-5 window which was also cooled to liquid nitrogen temperature. The detector signal was amplified, synchronously rectified and brought out at three different levels of amplification in order to have sufficient dynamic range to obtain data over the radiance range encountered during a balloon flight. The data handling was similar to that employed with the transmission instrumentation.

The third instrument used in these studies was a small filter wheel radiometer. This unit used a five position filter wheel which was rotated directly behind the entrance aperture. A tuning fork chopper was placed directly in front of the entrance aperture and interrupted the incoming radiation at a 150 Hz rate. The radiation entering the aperture was imaged on a Ge:Cu detector. This instrument was also cooled to liquid nitrogen temperatures. A frost prevention system similar to that used on the spectrometer was also used on this instrument. The detector signal was amplified, synchronously rectified and recorded at three different levels. This instrument was flown in conjunction with the cold grating spectrometer and the data handling was the same as that for the grating spectrometer.

III. FLIGHT DETAILS

The data presented in this report were obtained during three balloon flights. The transmission data were obtained during a flight made December 6, 1970, and the emission data were obtained during flights made February 22, 1971, and April 23, 1971. The details concerning the flights are given in Table I. In all cases a $2 \cdot 10^6$ ft^3 balloon was used as a vehicle and data were taken from the ground through float altitude.

IV. DATA REDUCTION

The magnetic tape recording system operated properly on all flights and these data were used in the data reduction since this allowed the data to be introduced directly into the computer without any intermediate processing. Data reduction is different for each of the three instruments, hence they are discussed separately below.

IV. 1. Transmission Flight

The detector amplifier recording system combination is designed to be linear over the total recording range of the magnetic tape recorder. The output signal voltage is proportional to the intensity of solar radiation reaching the spectrometer at the wavelength region being passed by the grating. The quantity of interest is the fractional transmittance versus wavelength. In order to determine this quantity it is necessary to determine what the signal would have been at the top of the earth's atmosphere. This is determined on the basis of the data obtained at float altitude where the absorptions are weak. In the wavelength region scanned during this flight the majority of the absorption is due to water vapor. Since the amount of water vapor decreases rapidly with altitude the residual absorptions at float altitude consist of a series of narrow lines and the envelope can be accurately determined. After the envelope was determined, the data were reduced to transmittance using the computer. Wavelength calibration was accomplished by using the positions of known atmospheric absorption lines. This allowed the data to be presented as the transmittance versus wavenumber curves presented below.

IV. 2. Spectral Radiometer

As in the case of the absorption spectrum an attempt was made to keep the overall system linear over the full recording range. In the case of this instrument the radiance levels varied over a range of 10^6 and it was not possible to achieve linearity over the full range; however, the non-linearity was confined to the high radiance values and these are associated with the lower altitude data. The signal voltage in this case was proportional to the difference

in radiance of the object being viewed at wavelength and the radiance of a 77° K blackbody at the same wavelength. Therefore the radiance of the sky at wavelength λ is given by

$$N(\lambda) = K(\lambda)\ V(\lambda) + N_{Ref}(\lambda T)$$

where $K(\lambda)$ is the calibration factor for the spectrometer and depends on λ, $V(\lambda)$ is the signal voltage measured with the instrument and $N_{Ref}(\lambda T)$ is the radiance of a blackbody at wavelength and temperature T where T is the temperature of the spectrometer system at the time the spectrum was taken. The calibration factor $K(\lambda)$ is determined from data obtained using a blackbody calibration source operated over a temperature range which covers radiance range observed during the balloon flights. The data were reduced by computer using the appropriate calibration factor.

IV. 3. Filter Radiometer

Reduction of the data obtained with the filter radiometer was performed in much the same way as for the spectral radiometer. In this case the relation is given by

$$\overline{N}_i = \overline{K}_i\ V_i + \overline{N}_{ref\ i}(T)$$

Here $\overline{N}_i$ is the average radiance in the wavelength region passed by the ith filter, K_i is the calibration factor for the ith filter, V_i is the observed signal voltage and $\overline{N}_{ref\ i}$ (T) is the average radiance of a black body in the filter region transmitted by the filter at temperature of the radiometer. Here

$$\overline{N}_i = \frac{\int_{\lambda_1}^{\lambda_2} N(\lambda)F_i(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} F_i(\lambda)d\lambda} \qquad \text{and}$$

$$\overline{N}_{ref\ i}(T) = \frac{\int_{\lambda_1}^{\lambda_2} N(\lambda T)F_i(\lambda)}{\int_{\lambda_1}^{\lambda_2} F_i(\lambda)d\lambda}$$

where $F_i(\lambda)$ is the filter transmission function.

V. RESULTS

V. 1. Atmospheric Transmittance

The instrumentation operated properly and solar spectra were obtained from the ground through floating altitude. Spectra were also obtained from float altitude while the sun set, i.e., at solar zenith angles greater than 90°. Since a spectral scan is accomplished every two minutes more than two hundred spectra were obtained during the flight. As the transmission is changing only slowly with altitude only selected spectra are presented. Figure 1 shows five spectra obtained during the ascent portion of the flight. These spectra were also obtained from float altitude (30 km) when the solar zenith angle was greater than 90°. Under these conditions, the radiation reaching the spectrometer has traversed a long path through the atmosphere at high altitudes. Since the amount of water vapor present at high altitude is small, the resultant spectra contain data which can not be obtained from lower altitudes. Figure 2 shows one such spectrum.

V.2. Emission Data

The spectral and filter radiometers were flown together on the flights launched on February 22 and April 23. Both instruments operated properly on the February 22 flight and data were obtained at all altitudes. Samples of the spectra obtained during the flight are given in Figures 3 through 8. These indicate the way the emission data vary with altitude. The data obtained with the filter radiometer are given in Figures 9 through 11. In this case the readings obtained with a particular filter during a cycle are averaged and the radiance corresponding to the reading is plotted as one data point. Filter transmission curves are given in Figure 12.

On the April 23 flight, the spectrometer drive motor stopped shortly after launch and no data were obtained with this unit. The filter instrument operated properly and data were obtained with it throughout the flight. These data are processed in the same way as for the February 22 flights. The data obtained during this flight are presented in Figures 13 through 17.

VI. ANALYSIS OF THE DATA

VI.1. Transmittances Data

The absorption features present in this region are due to H_2O, CO_2, and N_2O with a weak absorption due to HNO_3. As mentioned above, the major absorptions beyond 18μ are due to water vapor and this is evident in the change in transmittance with altitude in this region. The spectra presented in Figure 1 illustrate this feature. By the time the balloon has reached 40,000 feet, only the strong water vapor lines still show significant absorption. The change in absorption from 40,000 feet through floating altitude is small reflecting the fact that the stratosphere is "dry" with a mixing ratio which varies with altitude. The data obtained have not been completely analysed so as to determine the total profile. This analysis will be completed and reported in a future report. The absorptions in the region between 16μ and 18μ are due mainly to CO_2 and N_2O. The strong absorption at 597 cm^{-1} evident in the higher altitude spectra is due to a CO_2 Q branch and that at 589 cm^{-1} is the fundamental of N_2O. The spectra obtained after the solar zenith angle reached 90^o contain additional absorption feature between 440 cm^{-1} and 480 cm^{-1} that enhance as the sun sets. These are evident as a rotational structure with a spacing of about 0.8 cm^{-1} at 448 cm^{-1} and 465 cm^{-1}. In addition there is an unresolved P, Q, R band structure from 430 cm^{-1} to 490 cm^{-1} with a strong Q occuring at 457 cm^{-1}. This is due to HNO_3, however, the Q branch absorption is enhanced by a group of water vapor lines that absorb strongly in the same region. The rotational structure which is superposed on the P and R absorptions does not appear to be due to HNO_3 since we have not been able to obtain similar structures in the laboratory using a Beckman IR-7 spectrometer in conjunction with sample cell containing HNO_3. The laboratory spectra do not exhibit any rotational structures similar to that observed in the sunset spectra.

VI.2. Emission Data

The spectral region covered during the emission flights is roughly the same as that covered during the transmittance flight and the remarks above concerning the gases present applies here. The information contained in these spectra and that contained in the absorption data are of course related.

The emission data have the additional interpretational problem that the observed radiances depend not only on the water vapor amount but also on the atmospheric temperature profile. In this case, it is also possible to determine a water vapor mixing ratio profile from the observed radiances if the temperature profile is known. Temperature data were available from the radiosonde run performed at Holloman just before the flight, however these data are only available up to 60,000 feet. A water vapor mixing ratio profile was determined on the basis of these data assuming that the temperatures above 60,000 feet were the same as those observed on other dates in the Holloman area. The result of this analysis is shown in Figure 18. This profile shows the characteristics similar to those observed on other flights. These are a rapid decrease in mixing ratic with altitude as the tropopause is approached. A minimum mixing ratio just above the tropopause and an increase in mixing ratio with altitude up to floating altitude. The minimum mixing ratio observed on this flight ($1. 10^{-6}$ g/g) is less than those observed by Mastenbrook during most of his recent flights from Washington, D. C.

In addition to the water vapor emission features the region also contains features due CO_2, N_2O and HNO_3. The HNO_3 emission shows up as an overall increase in emission in the region from 21μ to 23μ and an enhancement in the emission at 21.5μ due to the strong Q branch of HNO_3 present here. The emission features at 16.2μ and 17μ are Q branches due to CO_2 and N_2O.

VII. CONTAMINATION EFFECTS

One of the major problems associated with measuring water vapor in the stratosphere is the possibility that the measurement is contaminated by water vapor carried aloft by the instrumentation and the balloon. This problem has been the subject of a great deal of discussion over the years and considerable misinformation currently exists concerning the role of the balloon in such contamination. The problem arises in large part because investigators fail to recognize that quite often the sources of contamination present in their own instrumentation are more apt to be the cause of any contamination which may be present than the balloon itself. As a result, the balloon has the erroneous reputation of being a large source of contamination. The use of the infrared absorptions and emissions to determine the water vapor mixing ratio

profile has the advantage that it is less subject to local contamination than point sensors which sample only the immediate vicinity of the sensor. The instrumentation and observing techniques used in this study further reduces the possible effects due to contamination as follows: 1) In the transmission case, the use of solar spectra obtained with solar zenith angle of close to 90° and larger results in very large optical paths and the effects of any absorption due to contamination are greatly reduced. In particular if one considers the change in optical path due to a small change in solar zenith angle, then the resulting change in water vapor absorption has to be due to the change in the amount of atmospheric water vapor. Such data allow one to determine the atmospheric water vapor mixing ratio. This analysis is in process for the data obtained during this flight and will be reported later.

2) Emissions Data. The instruments used to obtain the emission data are operated at liquid nitrogen temperatures and the boil off dry nitrogen gas is vented out through the front of the instrument. This removes any water vapor from the optical path inside the instrument and probably also a considerable distance in front of the instrument. Thus the effects of contamination should be greatly reduced. The lack of contamination effects is evident in the data obtained during the balloon flights with these instruments. During the February 22 flight the instrumentation was allowed to remain at float altitude for several hours without any significant variation in emission indicating no significant contribution to the emissions due to local effects. In addition, on the April 23 flight data were obtained during the descent portion of the balloon flight and the data obtained during descent agree to within the experimental error with the data obtained during the ascent. This agreement tends to rule out any contamination effect since it is difficult to envision a contamination process which would remain constant under this type of variable conditions. On the basis of these observations, it is felt that the radiances and water vapor mixing ratios determined from the data reported here represent ambient water vapor conditions and are not contaminated.

TABLE I

BALLOON FLIGHT DETAILS

Date	Launch Time	Ascent Rate	Profile
December 6, 1970	1326 MST	250 m/min.	Ascend to float
February 22, 1971	0402 MST	230 m/min.	Ascend to float
April 23, 1971	0145 MST	270 m/min.	Ascend to float descend to 60,000

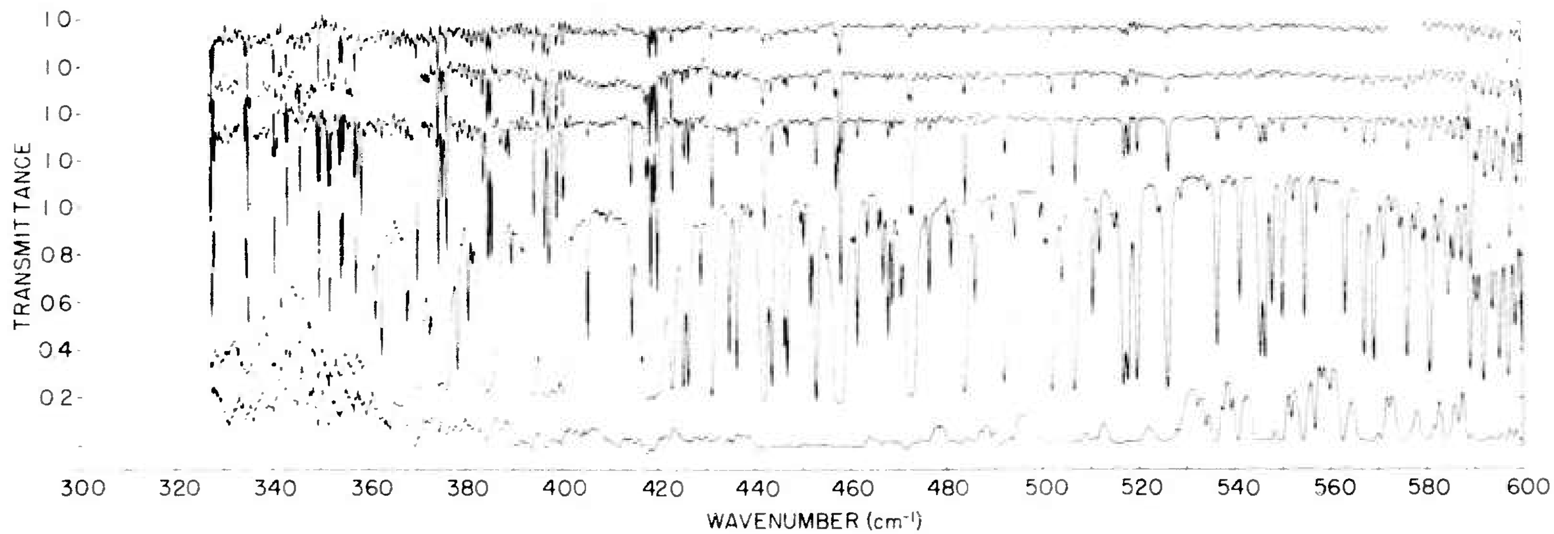

Figure 1 Infrared Solar Spectrum as observed from various altitudes. The spectra are sequentially offset in transmittance by 0.2 for clarity. The spectra were observed at the altitudes and solar zenith angles listed below, in sequence from the bottom of the figure to the top: 4.2 kft, 59.5°; 20.0 kft, 61°; 37.3 kft, 63°; 67.2 kft, 73°; and 97.0 kft, 85°.

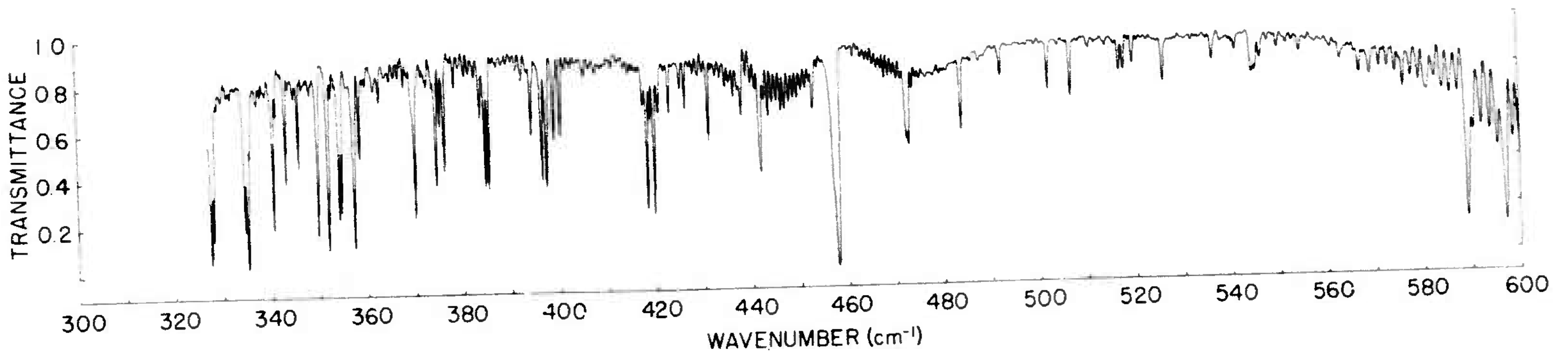

Figure 2 Infrared Solar Spectrum as observed from 97,000 ft. as the sun set. Solar zenith angle 93°, optical path 3.5 air mass.

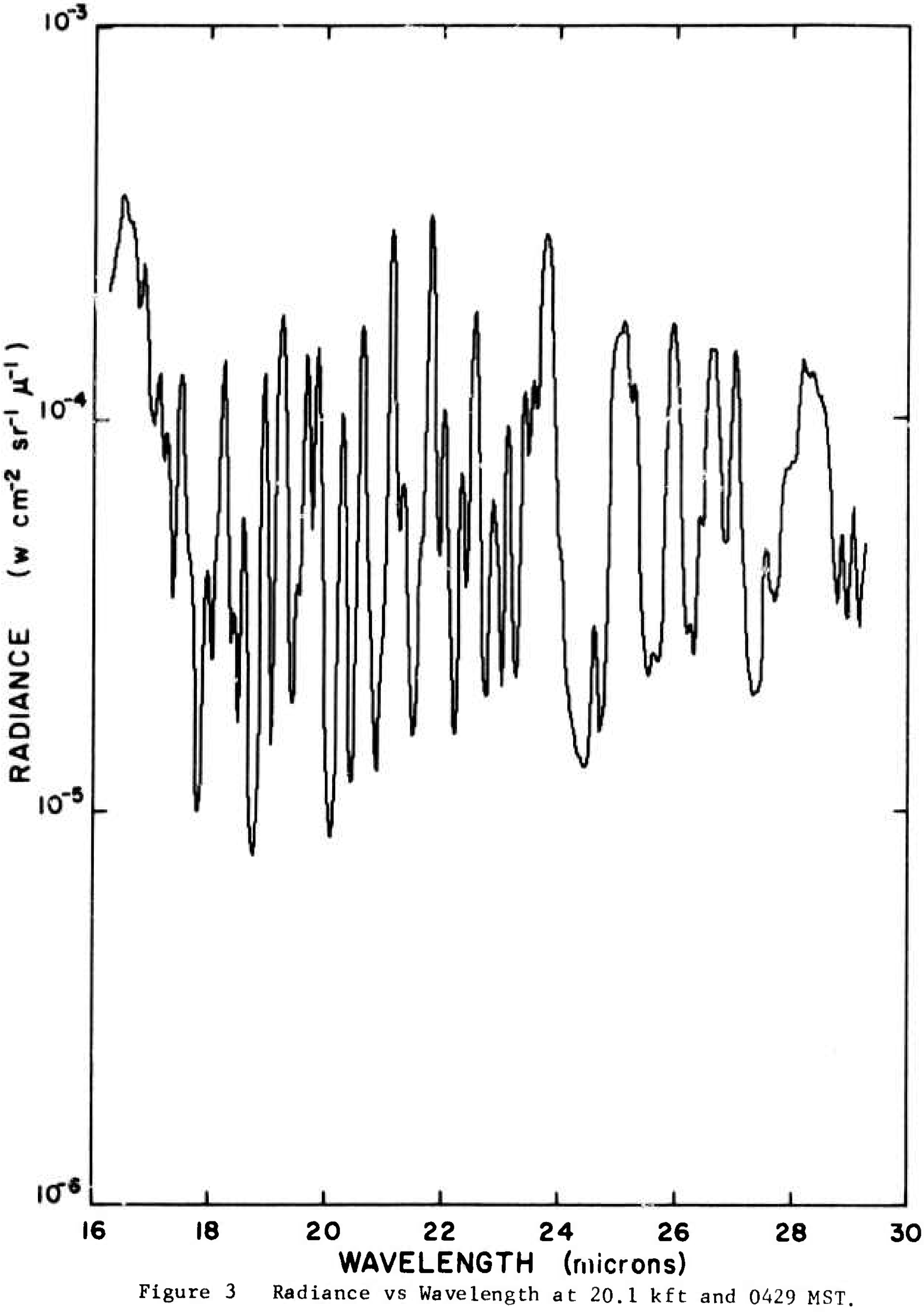

Figure 3 Radiance vs Wavelength at 20.1 kft and 0429 MST.

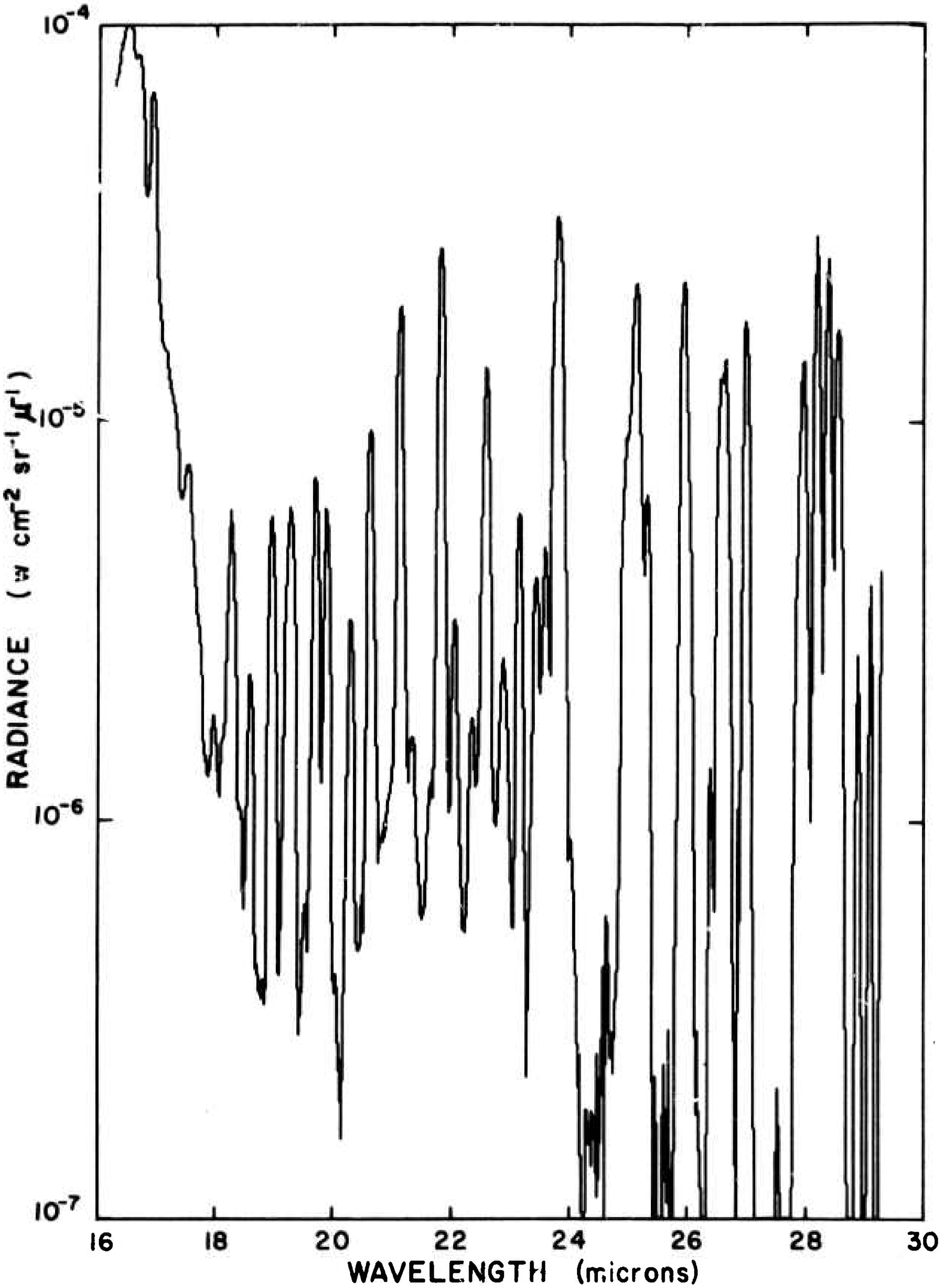

Figure 4 Radiance vs Wavelength at 31.3 kft and 0450 MST.

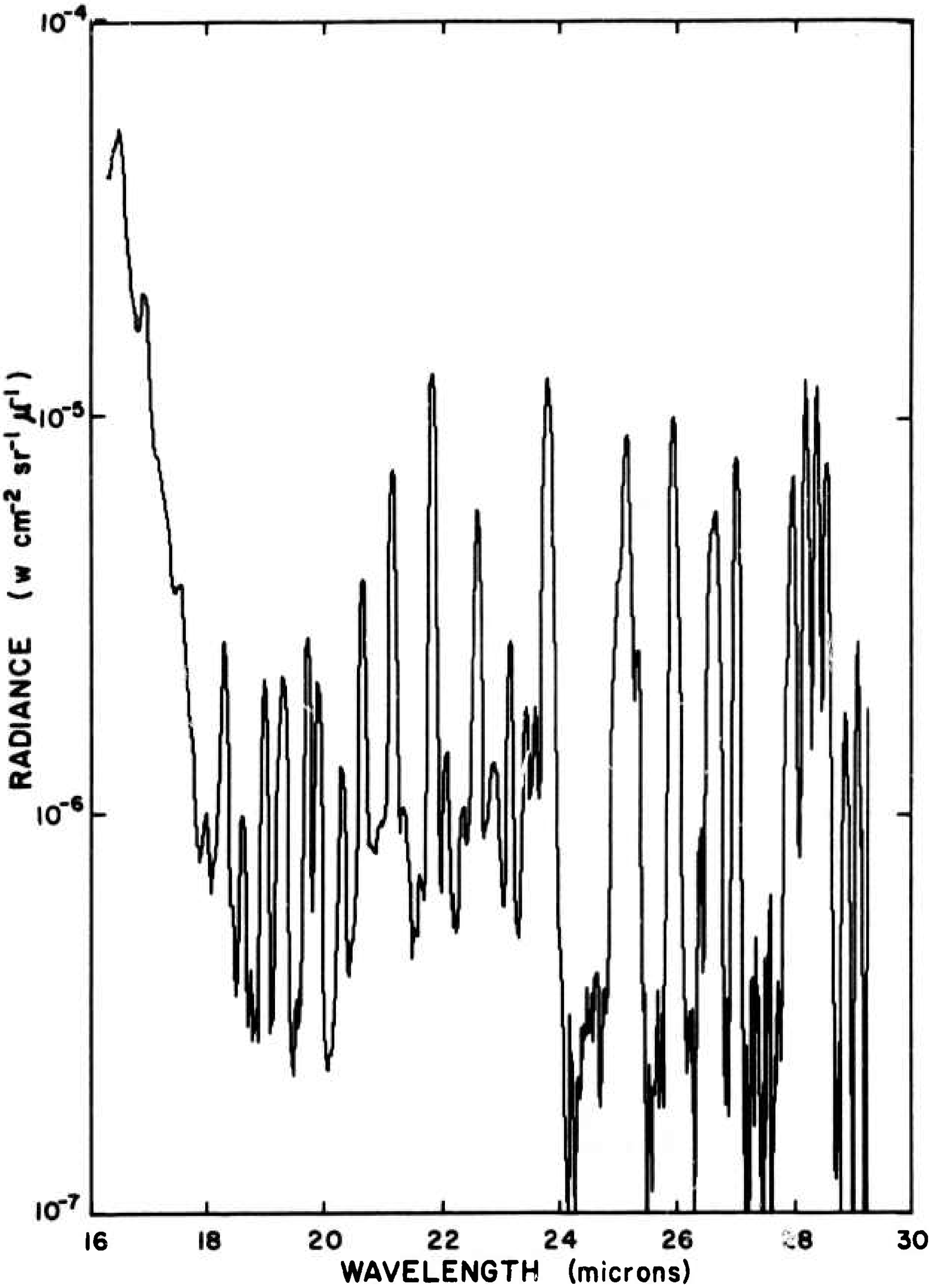

Figure 5 Radiance vs Wavelength at 40.9 kft and 0508 MST.

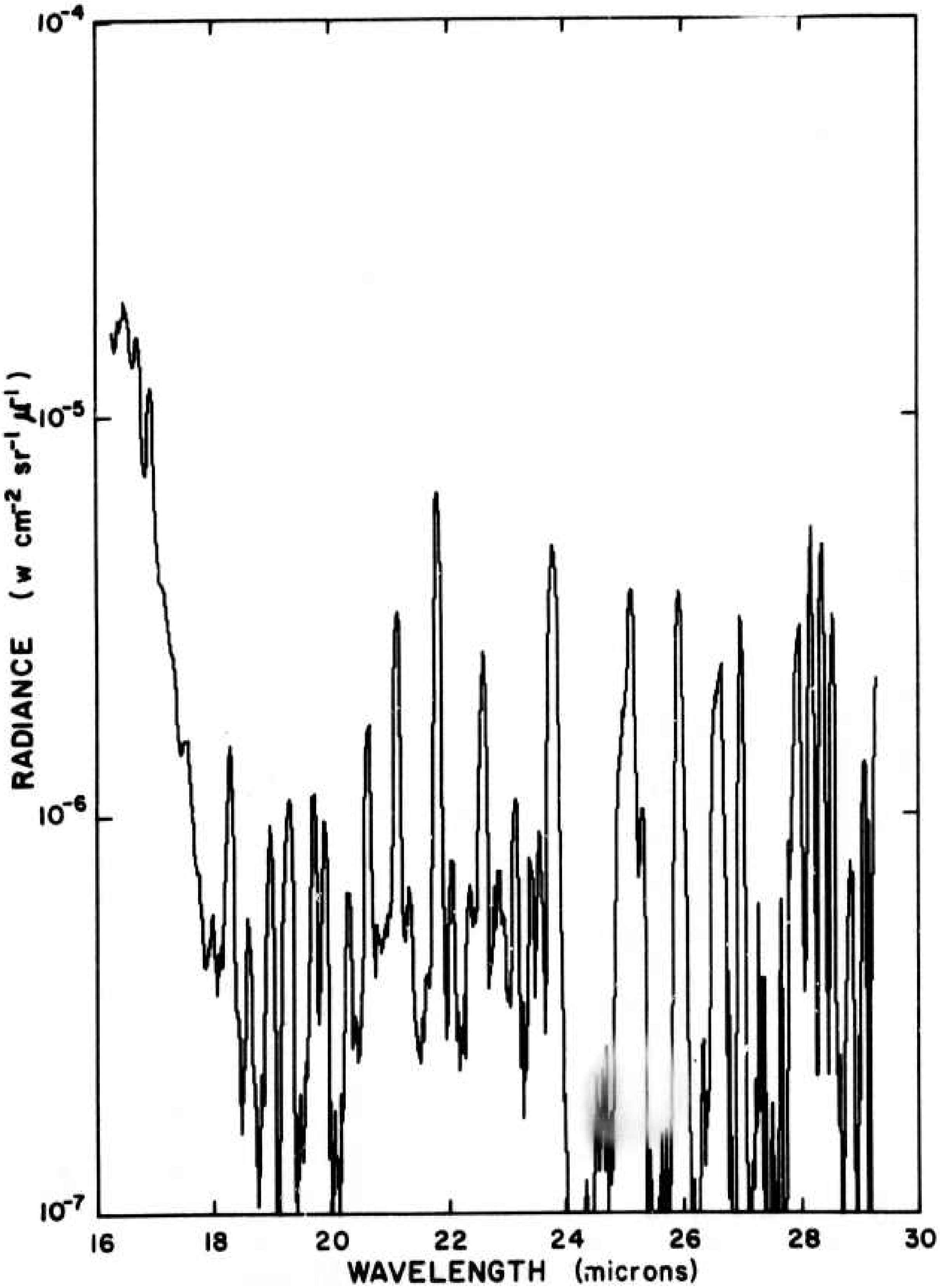

Figure 6 Radiance vs Wavelength at 70.2 kft and 0607 MST.

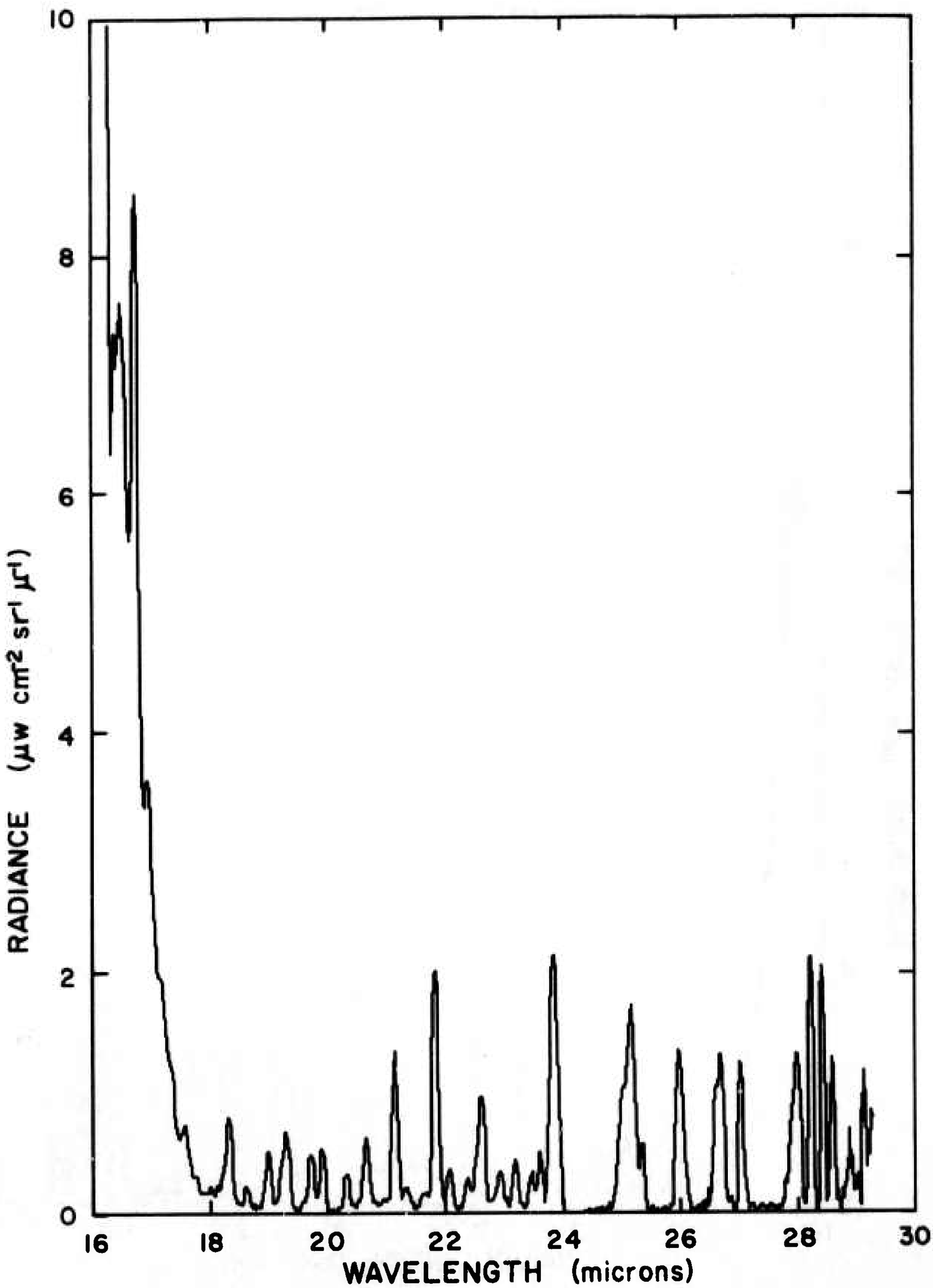

Figure 7 Radiance vs Wavelength at 96.0 kft and 0709 MST.

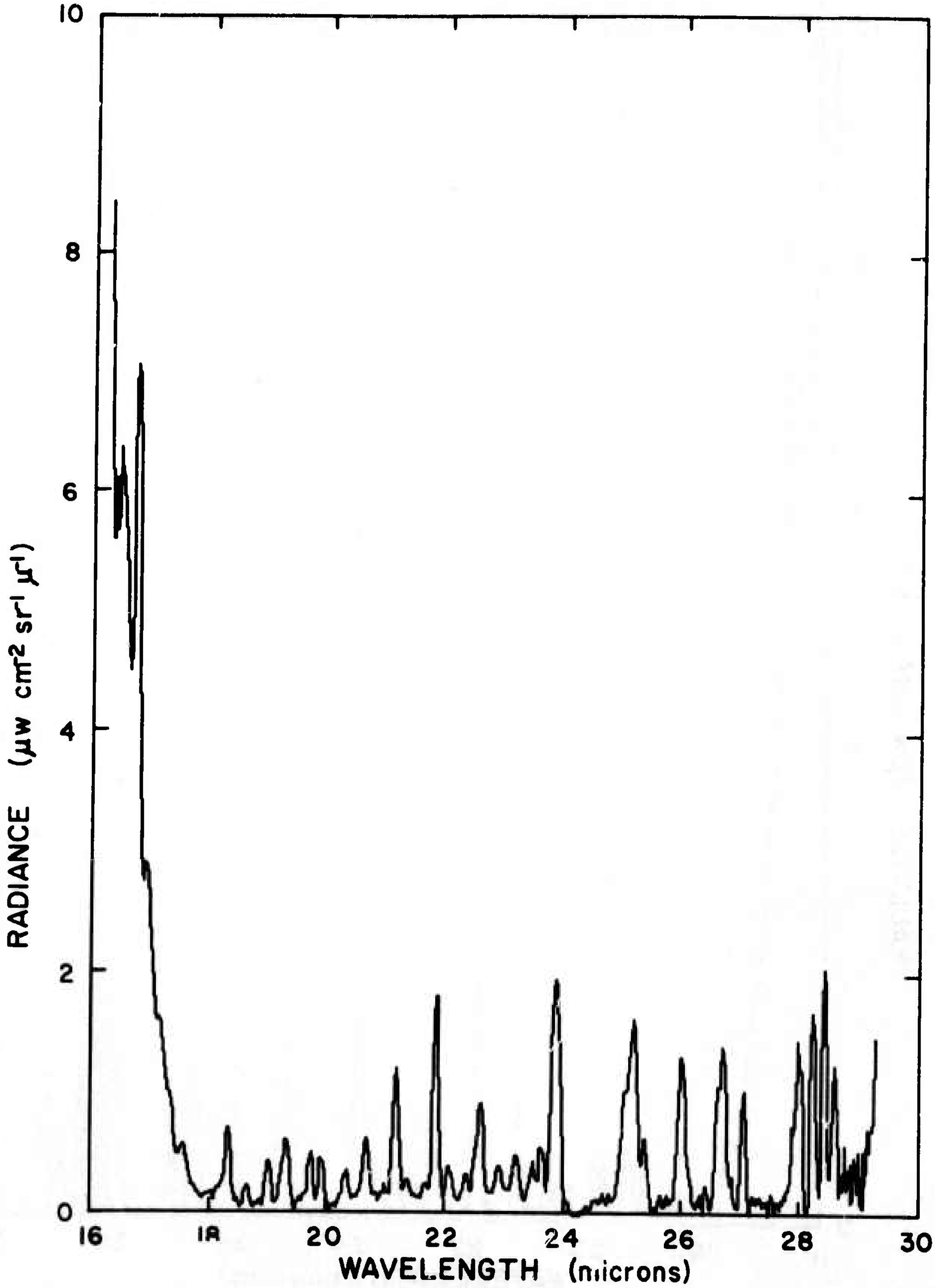

Figure 8 Radiance vs Wavelength at 96.0 kft and 0905 MST.

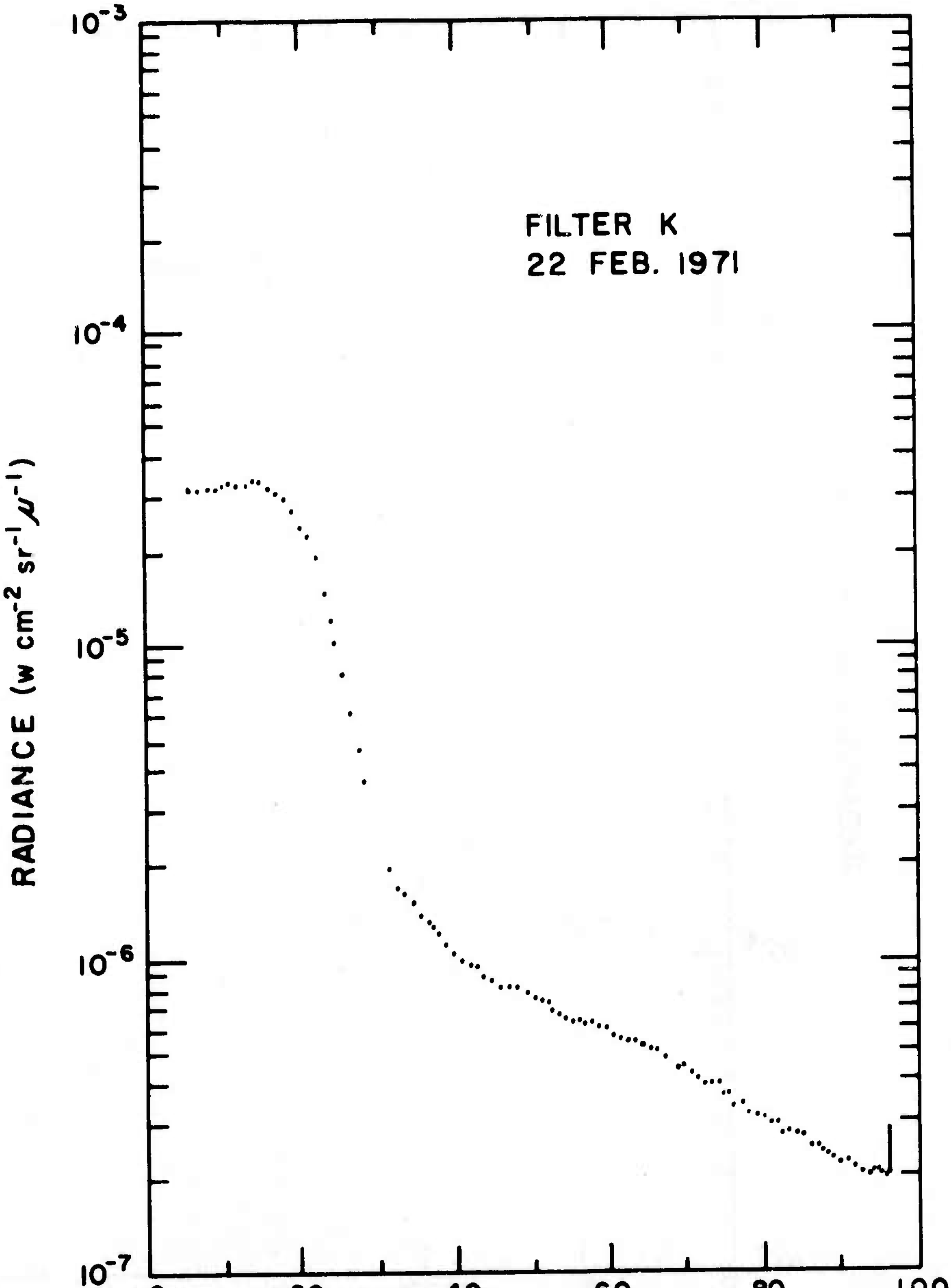

Figure 9 Radiance vs Altitude for Filter K.

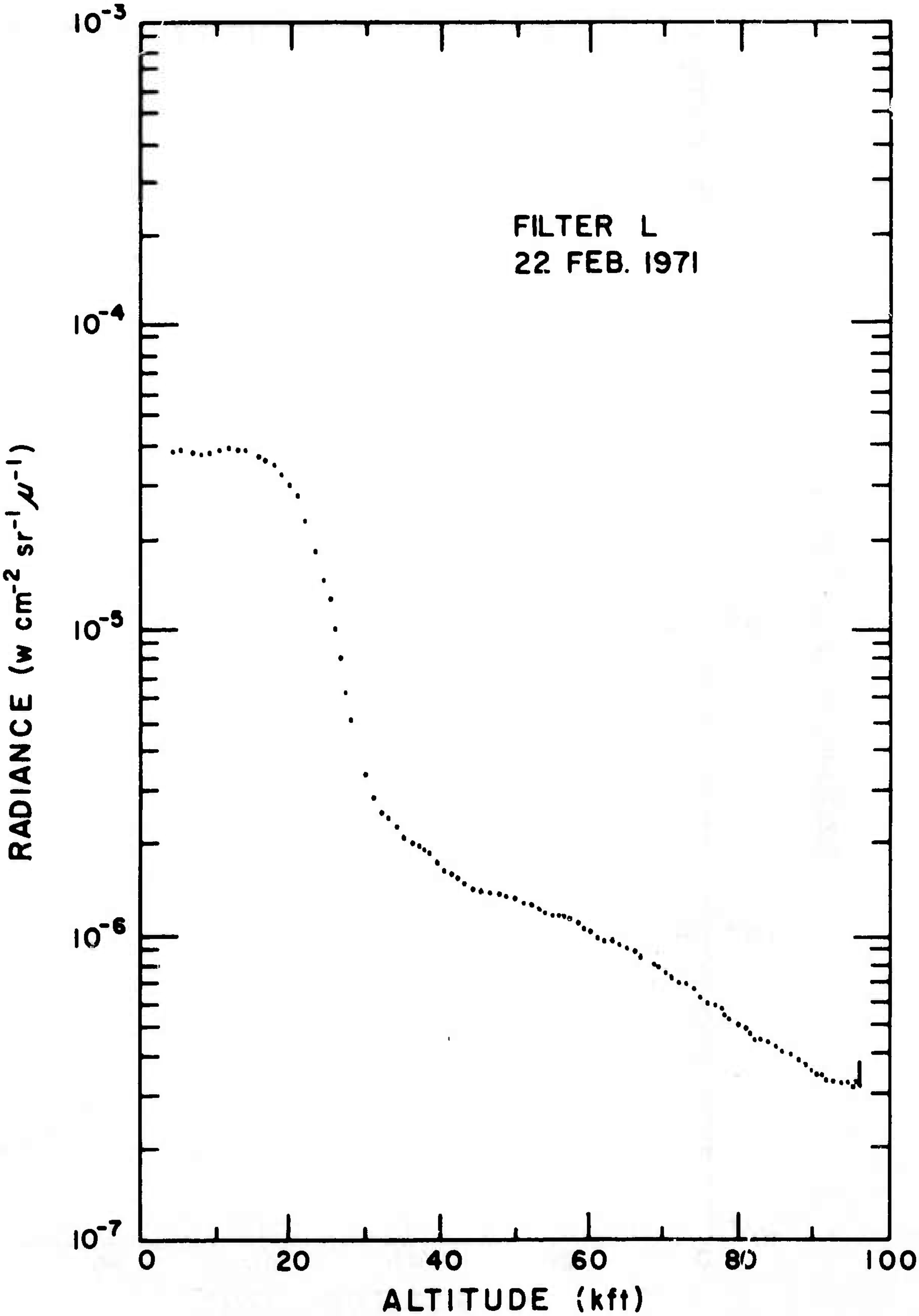

Figure 10 Radiance vs Altitude for Filter L.

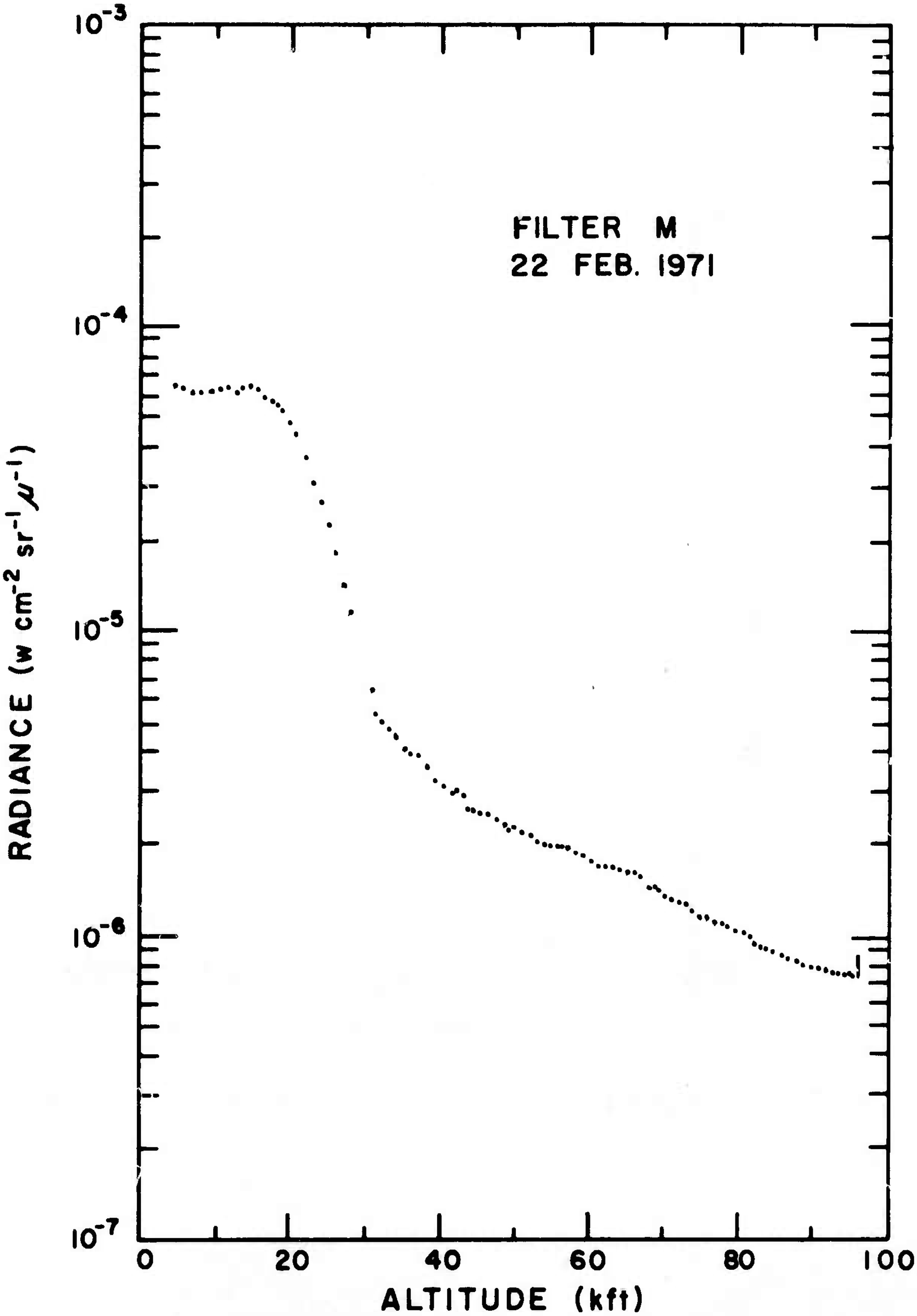

Figure 11 Radiance vs Altitude for Filter M.

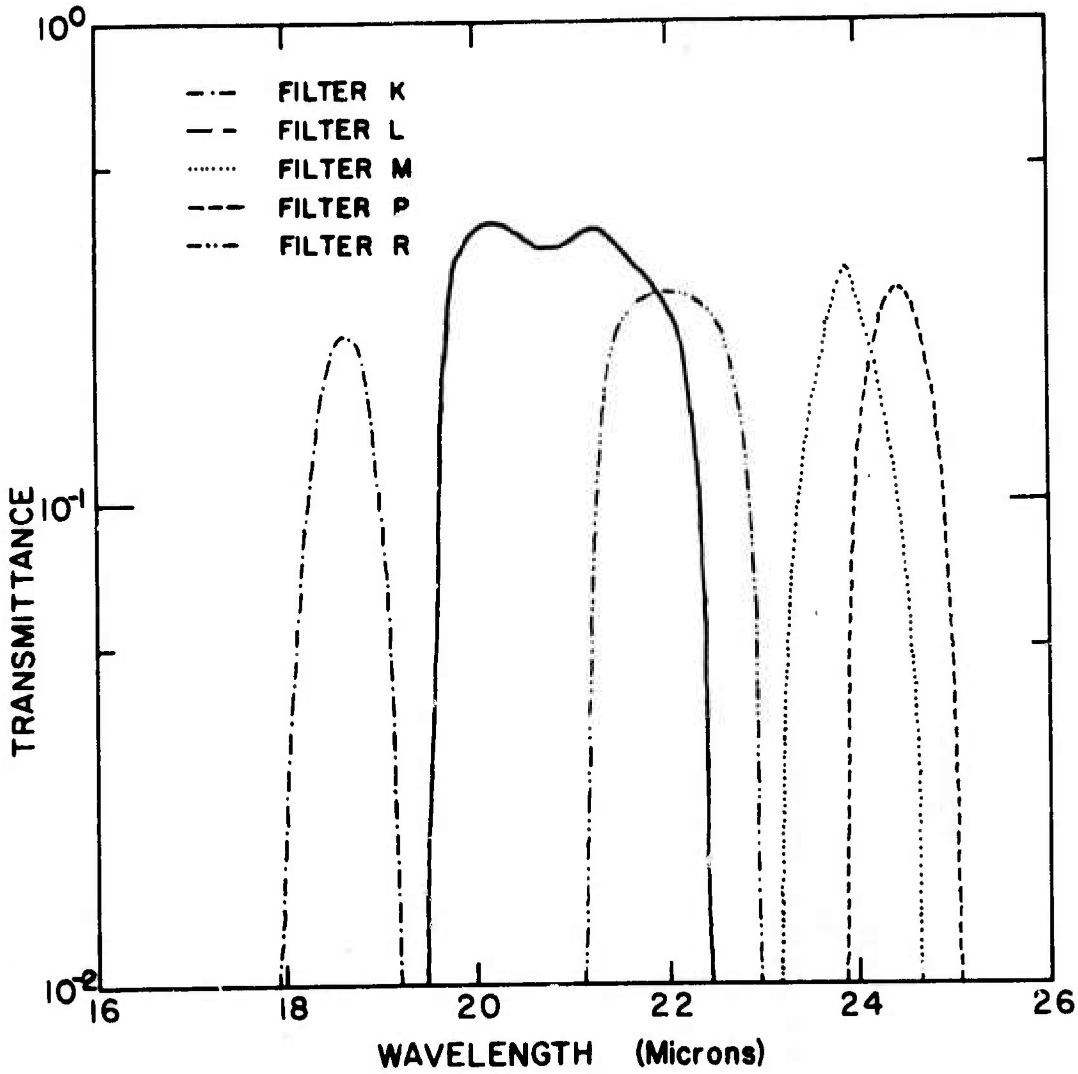

Figure 12 D. U. Radiometer Filter Curves for 23 April 1971

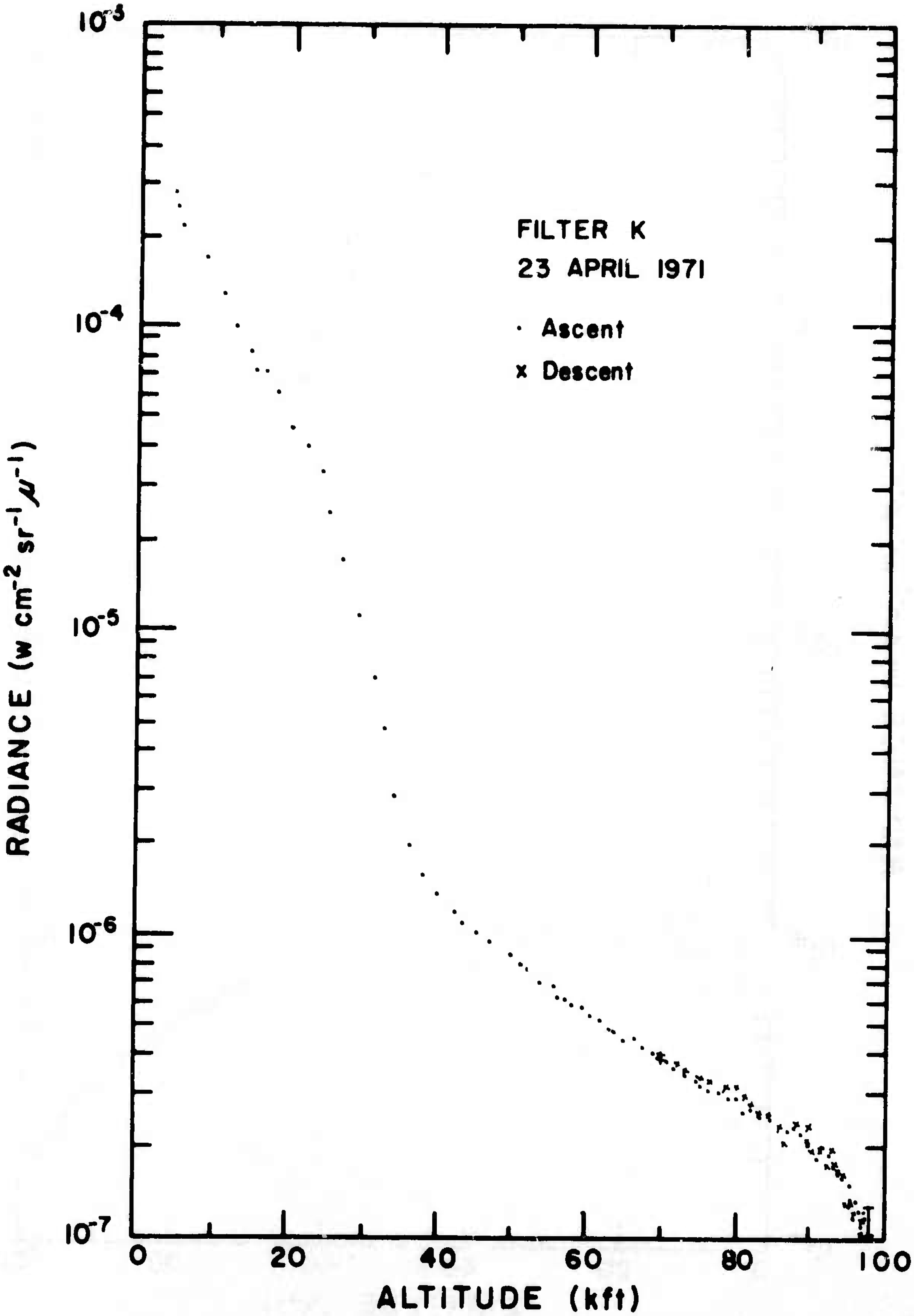

Figure 13 Radiance vs Altitude for Filter K.

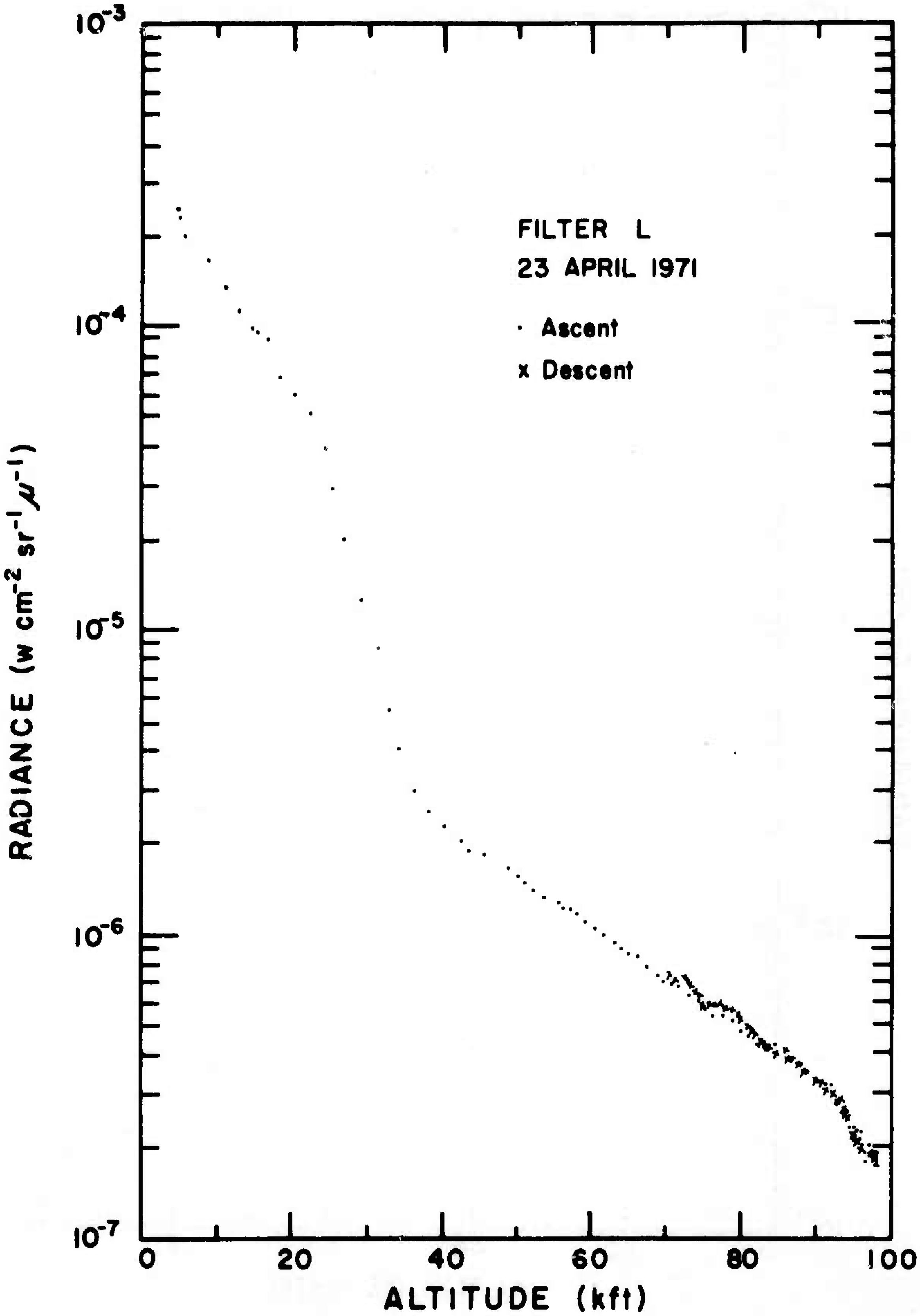

Figure 14 Radiance vs Altitude for Filter L.

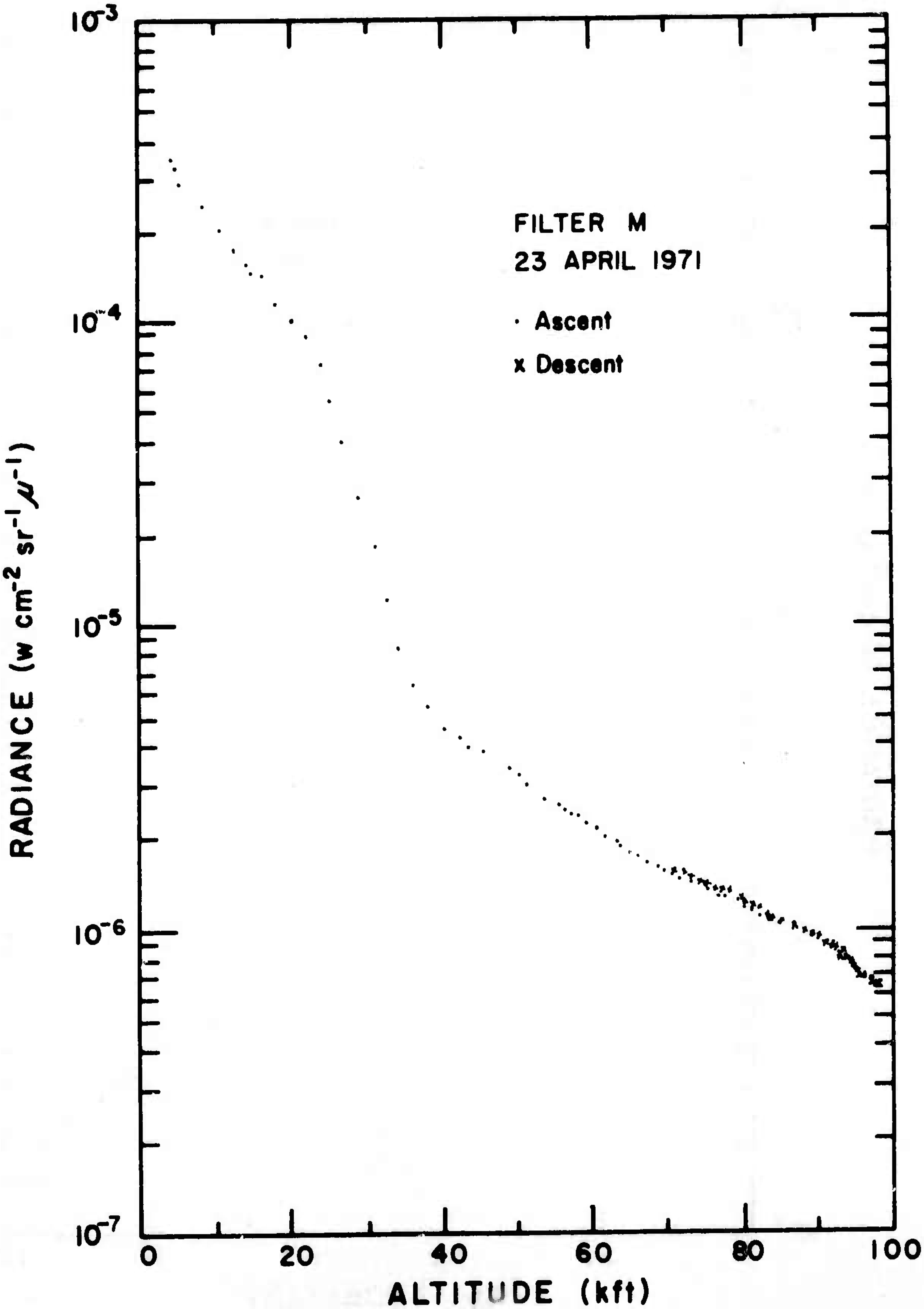

Figure 15 Radiance vs Altitude for Filter M.

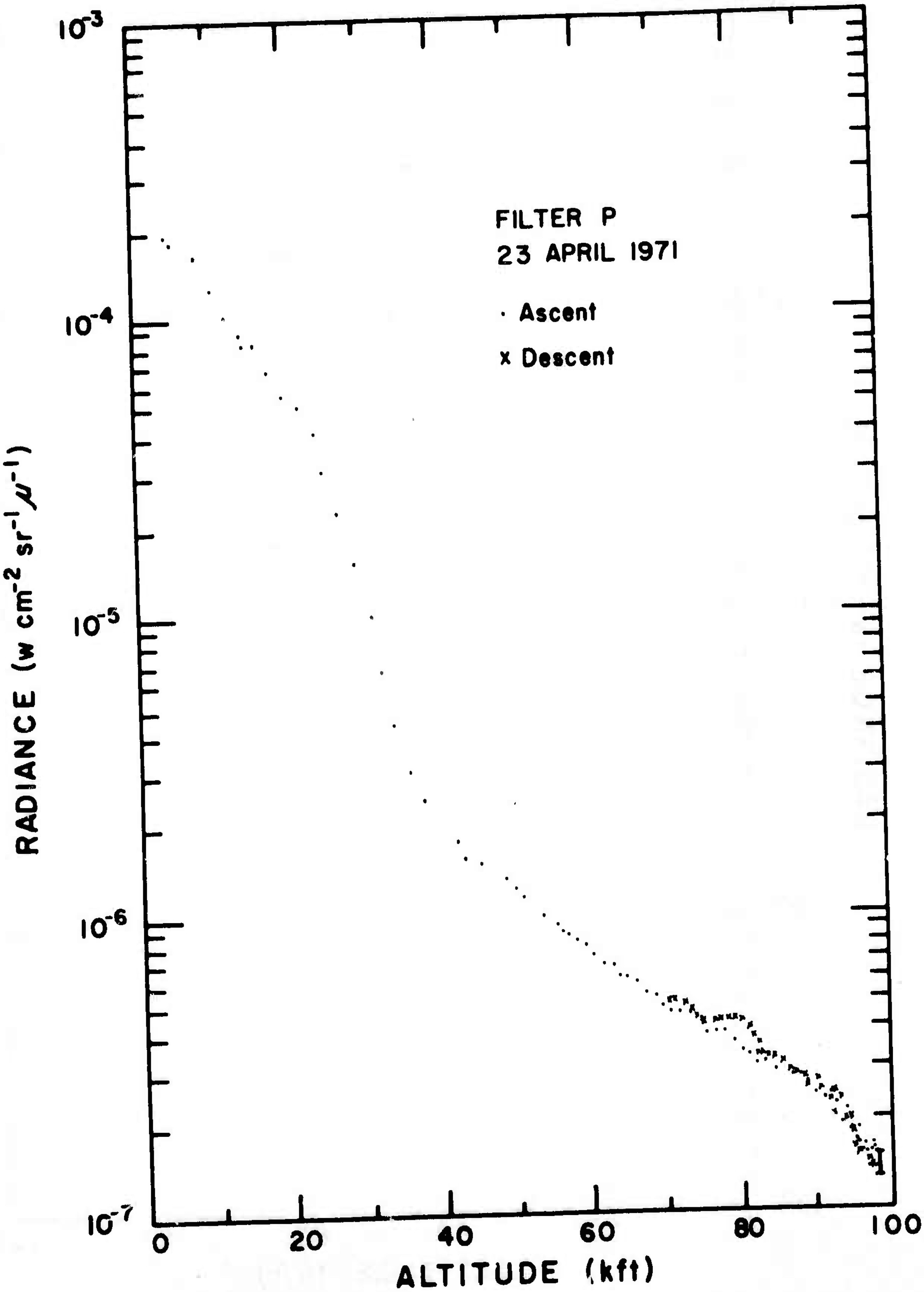

Figure 16 Radiance vs Altitude for Filter P.

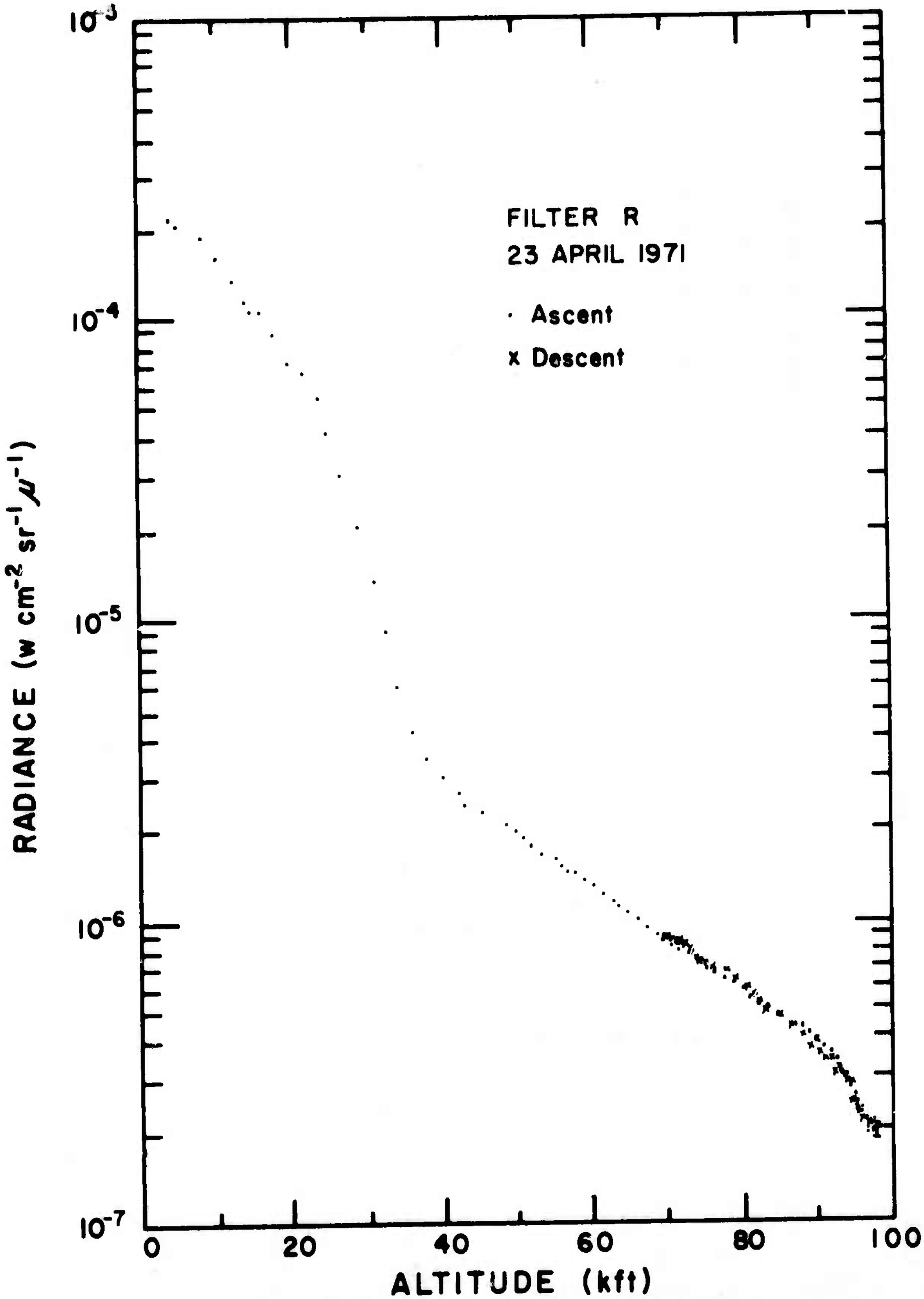

Figure 17 Radiance vs Altitude for Filter R.

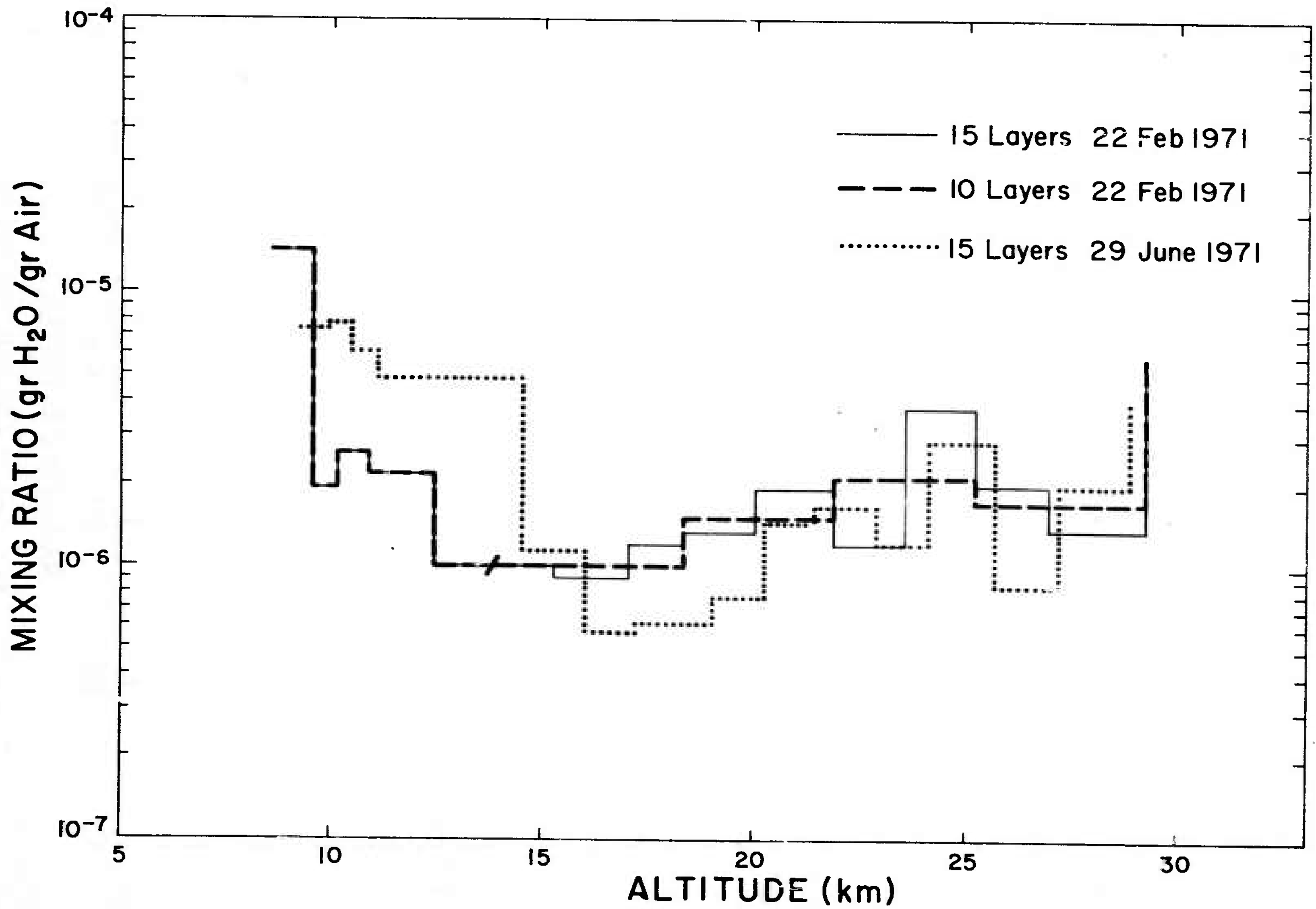

Figure 18. Water vapor mixing ratio profile as determined from the emission data. The data from the February flight were reduced using a 10 layer model and a 15 layer model.

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13. ABSTRACT

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